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TECHNICAL REPORT 5

DOG-LEG UNMASKING IN THE CORRECTED-INTERCEPT MODE

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1. INTRODUCTION

Dog-leg unmasking was proposed in reference (a) as a means of getting the torpedo out of the masking zone so that the target could be tracked in the post-launch period, even when the torpedo is much louder than the target submarine. A preliminary study was made in reference (a) of the effects of the maneuver on post-launch control in the corrected-intercept mode and in the bearing-rider mode.

The acquisition probabilities depend on a number of control parameters that the operator can choose. A study of the effects of these parameters, which was started in reference (a), was made recently in preparation for a submarine-submarine engagement model. Some results for the corrected-intercept mode, which is the more effective of the two control modes when dog-leg unmasking is used, are reported below.

2. DOG-LEG UNMASKING

Parameters and procedures that describe the unmasking operation, and which are under the control of the operator are the following:

a. Length of initial torpedo leg and method of computing it,

b. Direction and magnitude of the turn,

c. Length of dog leg and method of computing it.

The length of the initial leg was made proportional (factor f_1) to the estimated range of the target at launch, as in reference (a). However, the method of computing the length of the dog leg was changed to the method described on page 3-11 of reference (a). After the torpedo is turned to the dog leg it is allowed to run on that course for a time interval that assures unmasking and enough tracking time before masking recurs to obtain at least one correction. After the sonar operator reports that he can track the target, the dog-leg course is continued for the time f_2T, where

T is the smoothing time used in computing bearing rates. The controller then turns the torpedo back to the initial course and applies the first correction, which is computed from the tracking data during the time f_2T and the time used in making the turn. This correction is not included in reference (a). Thereafter, corrections are applied at intervals of length $C\Delta t$ until masking recurs, as in reference (a). We want to find good values for f_1 and f_2.

Our model allows the turn to the dog leg to be made in either direction but does not provide a rule for the controller to use. We had conjectured that the turn should be made in the direction of target motion, that is, to the right (left) when the target is moving right (left). Our best estimate of the direction of target motion at the time the turn must be ordered is the sign of $\hat{U}_b$, our estimate of the normal component of motion at launch.

To avoid having too many parameters to optimize we use an arbitrary value of 72 degrees for θ_d, the angle of the turn. Previous tests had indicated that angles between 60 and 80 degrees are good values and that the acquisition probability is not very sensitive to values of θ_d in this range. Larger angles can be used to reduce the time required to unmask, at the cost of a longer torpedo track. The optimum value for the angle θ_d is a compromise between the two effects.

3. TEST CONDITIONS AND PROCEDURES

The acquisition model for the corrected-intercept mode, described in reference (a), was revised to include the above changes. Again, we used the five evasive maneuvers that had been used in the earlier tests. The maneuvers are as follows:

Run	Maneuver
1	60 degrees turn away
2	60 degrees turn towards
3	120 degrees turn away
4	120 degrees turn towards
5	Decelerate from 10 knots to 4 knots and then accelerate back to 10 knots

In each run type the target submarine starts at a range of 10,000 yards from own submarine, runs at 90 degrees for a time interval, and then maneuvers, starting at the times at which the position of own submarine is that listed below:

Case	Position of Tracking Submarine
1	Middle of second tracking leg
2	Start of third tracking leg
3	End of third tracking leg
4	Middle of fourth tracking leg, if made
5	Start of fifth tracking leg, if made

Since three tracking legs are run before a solution can be obtained and tested, the maneuvers occur during the tracking interval in cases 1 and 2, just at the end of the tracking interval in case 3, and after the tracking interval in cases 4 and 5, provided an acceptable solution is obtained in three tracking legs. In cases 1 and 2 an acceptable solution sometimes requires 4 or 5 tracking legs.

In determining a rule for the direction of the turn, four additional maneuvers were used as follows:

Run	Maneuver
6	Turn +90 degrees from course 45 degrees to 135 degrees
7	Turn -90 degrees from course 45 degrees to -45 degrees
8	Turn -90 degrees from course 135 degrees to 45 degrees
9	Turn +90 degrees from course 135 degrees to 225 degrees

The same 5 cases for starting times were used with these run types.

A large number of parameters describing the performance of the sonar, the control procedures, and the torpedo are needed. The values used for these parameters are the same as those used in reference (a), some of which are listed in Table 3.1 of reference (a). A major limitation of this set of parameter values is that the biases in the error distributions have been put equal to zero. Some of these biases, such as the delta biases and the

biases in the running errors of the torpedo, can produce large miss distances. The miss distances produced by delta biases were studied in reference (b). Although our model permits the insertion of arbitrary values for these biases, we have used zero values here to permit a comparison of our results with those of reference (a).

Our models include the choice of zero or a computed value for the estimate $\hat{U}_r$ of the range component of velocity. The results given below are obtained with computed value of $\hat{U}_r$. The analysis in reference (a) indicated that the acquisition probabilities for the two TMA methods are nearly equal. The computed value of $\hat{U}_r$ is used here by chance; in revising the program we happened to choose the card deck for the computed value of $\hat{U}_r$. A check will be made by repeating some calculations with $\hat{U}_r = 0$.

4. OPTIMIZATION OF PARAMETERS

Our analysis in reference (a) indicated that the acquisition probabilities are sensitive to the length of the initial leg. Hence, we started with the f_1 parameter, using $f_2 = 1.0$ and the dog-leg turn in the direction of initial target motion.

Results for the run types 1 - 5 are presented in Table 1. The maximum values and nearly maximum values are underscored. It is evident that the maximum value usually is obtained with $f_1 = 0.2$ or $f_1 = 0.3$, rather than with $f_1 = 0.4$ as reported in reference (a). The change is produced by the change in the method of computing the length of the dog leg, to be certain that unmasking has occurred.

Significantly better values are obtained with $f_1 = 0.2$ than with $f_1 = 0.3$ in cases 1 and 2 of run 4, when the target turns almost directly toward the tracking submarine, and executes the turn during the tracking interval. As shown by the fact that k (the number of tracking legs before firing) is 5 in those cases, the torpedo is fired late. The small value of f_1 makes

TABLE 1. EFFECT OF LENGTH OF INITIAL LEG (f_1 times range estimate)

(f_2 = 1.0, δ = + 1

Run	Case	k	Acquisition Probability f_1=0.2	f_1=0.3	f_1=0.4	f_1=0.6
1	1	4	.39	.37	.34	.31
(90/30)	2	3	.47	.49	.49	.44
	3	3	.56	.55	.54	.40
	4	3	.56	.56	.52	.43
	5	3	.56	.56	.53	.45
2	1	3	.60	.59	.45	.00
(90/150)	2	3	.67	.70	.67	.42
	3	3	.72	.72	.72	.36
	4	3	.72	.71	.70	.37
	5	3	.69	.70	.68	.50
3	1	5	.32	.29	.27	.24
(90/-30)	2	5	.35	.32	.31	.27
	3	3	.54	.53	.53	.52
	4	3	.55	.55	.54	.52
	5	3	.47	.56	.54	.51
4	1	5	.74	.66	.53	.00
(90/210)	2	5	.72	.63	.48	.00
	3	3	.73	.73	.70	.00
	4	3	.73	.71	.69	.29
	5	3	.60	.68	.68	.48
5	1	3	.63	.62	.59	.39
(Dec./Acc.)	2	3	.60	.63	.59	.66
	3	3	.65	.65	.63	.53
	4	3	.65	.65	.63	.53
	5	3	.64	.65	.60	.53

it less likely that the torpedo will pass the target before it is enabled. With $f_1 = 0.6$ the torpedo is almost certain to have passed the target before enabling in these two cases.

Significantly better values are obtained with $f_2 = 0.3$ than with $f_2 = 0.2$ in case 5 of runs 3 and 4, when the target makes a large turn 200 seconds after the torpedo has been fired. Similar results are obtained for somewhat larger delays. Here, the use of the larger value of f_1 permits the corrections to be applied at a more advantageous time relative to the time at which the turn is executed. We have chosen $f_1 = 0.3$ for use here and in our later work, since the cases in which 0.3 is better than 0.2 appear to be more likely to occur than those in which 0.2 is better than 0.3.

The sensitivity test for f_2, with $f_1 = 0.3$ and the dog-leg turn in the direction of initial target motion, is shown in Table 2. For most cases the acquisition probability is not very sensitive to f_2. In a few cases, such as case 1 of run 2, there is an indication that values of f_2 smaller than 0.5 might be better than those used. For these cases, and some others as well, still better results are obtained with no unmasking and no post-launch control; the column headed "No Control" lists the acquisition probabilities when no attempt is made to unmask and no corrections are applied.

Significantly better results are obtained with $f_2 = 1.0$ or 1.5 than with $f_2 = 0.5$ in case 5 of runs 3 and 4, when the target makes a large turn at a time during the dog leg. With $f_2 = 0.5$ masking recurs before many bearing observations can be obtained when the target is on the new course. On balance, the value $f_2 = 1.0$ appears to be a good choice.

The effect of the direction of the dog leg is shown in Table 3, using $f_1 = 0.3$ and $f_2 = 1.0$. In addition to the acquisition probabilities for the dog leg in the two directions we list the sign of U_b, the value of the normal component of velocity at the time the torpedo was fired. In the column headed "sign parity" we indicate by an X the cases in which the optimal direction for the dog leg is opposite to the direction of target motion indicated by U_b.

TABLE 2. EFFECT OF UNMASKING TIME (f_2T)
(f_1 = 0.3, δ = + 1)

Run	Case	Acquisition Probability f_2=0.5	f_2=1.0	f_2=1.5	No Control
1	1	.38	.37	.35	.34
(90/30)	2	.52	.49	.48	.48
	3	.54	.55	.53	.46
	4	.56	.56	.54	.50
	5	.55	.56	.55	.54
2	1	.76	.59	.56	.78
(90/150)	2	.71	.70	.68	.74
	3	.75	.72	.72	.69
	4	.72	.71	.70	.67
	5	.69	.70	.69	.64
3	1	.30	.29	.28	.32
(90/-30)	2	.34	.32	.31	.34
	3	.55	.53	.52	.32
	4	.56	.55	.53	.42
	5	.44	.56	.55	.51
4	1	.69	.66	.67	.80
(90/210)	2	.66	.63	.63	.78
	3	.73	.73	.72	.57
	4	.73	.71	.71	.62
	5	.59	.68	.68	.64
5	1	.63	.62	.61	.59
(Dec./Acc.)	2	.63	.63	.61	.57
	3	.66	.65	.64	.59
	4	.65	.65	.63	.59
	5	.65	.65	.63	.59

TABLE 3. EFFECT OF DIRECTION OF TURN
(f_1 = 0.3, f_2 = 1.0)

Run	Case	Acquisition Probability Right Turn	Acquisition Probability Left Turn	Sign U_b	Sign Parity
1	1	.37	.42	+	X
(90/30)	2	.49	.50	+	X
	3	.55	.49	+	
	4	.56	.51	+	
	5	.56	.54	+	
2	1	.59	.70	+	X
(90/150)	2	.70	.73	+	X
	3	.72	.70	+	
	4	.71	.68	+	
	5	.70	.66	+	
3	1	.29	.41	-	
(90/-30)	2	.32	.46	-	
	3	.53	.50	+	
	4	.55	.55	+	
	5	.55	.58	+	X
4	1	.66	.81	-	
(90/210)	2	.63	.80	-	
	3	.73	.68	+	
	4	.71	.69	+	
	5	.68	.68	+	
5	1	.62	.57	+	
(Dec./Acc.)	2	.63	.60	+	
	3	.65	.59	+	
	4	.65	.59	+	
	5	.65	.59	+	

It is seen that the optimal direction of the dog-leg turn usually is that of the indicated target motion. The principal exceptions are case 1 of run 1 and case 1 of run 2, in which the target executes a moderate turn during the tracking interval, turning from a course (90 degrees) that is strongly directed to the right to a course (30 or 150 degrees) that is less strongly directed toward the right. In the other cases in which the optimal direction is opposite that of U_b the acquisition probabilities in the two directions are nearly equal.

To test the direction rule of turning in the direction indicated by $\hat{U}_b$ we made the additional runs numbered 6 - 9, as described in section 3 above. In runs 6 and 8 a 90-degree turn is made so that U_b after the turn is essentially the same as before the turn. In runs 7 and 9 a 90-degree turn is made in ways that reverse the sign of U_b.

The results are shown in Table 4. Again, the optimal direction usually is the same as the direction of the target motion indicated by the sign of U_b. In only one of the three exceptions, that of case 1 in run 9, is there a large difference in acquisition probabilities.

A comparison of the acquisition probabilities presented above with those listed in reference (a) shows that the values are nearly equal, except for case 1 of the five run types and case 2 in runs 1 through 4. The old values are significantly larger for case 1 of the five run types, when the maneuver is started at the middle of the second tracking leg. The main reason that differences occur in the acquisition probabilities is that the two methods of computing the dog leg are different. With the old method, in which the length of the dog leg was made proportional to the estimated range, the optimal value of the proportionality factor was small, and often too small to unmask the target. By chance alone the torpedo often was put on a good course for acquisition for the particular set of runs chosen; for the initial course of 90 degrees almost any maneuver decreases the lead angle for interception. The fact that the old probabilities are higher than

TABLE 4. EFFECT OF DIRECTION OF TURN (continued)
(f_1 = 0.3, f_2 = 1.0)

Run	Case	k	Acquisition Probability Right Turn	Acquisition Probability Left Turn	Sign U_b	Sign Parity
6	1	3	.76	.68	+	
(45/135)	2	3	.62	.64	+	
	3	3	.66	.61	+	
	4	3	.65	.58	+	
	5	3	.62	.54	+	
7	1	4	.15	.40	-	
(45/-45)	2	5	.27	.41	-	
	3	3	.47	.42	+	
	4	3	.44	.44	+	
	5	3	.44	.45	+	X
8	1	3	.57	.54	+	
(135/45)	2	3	.62	.60	+	
	3	3	.67	.50	+	
	4	3	.71	.68	+	
	5	3	.75	.73	+	
9	1	5	.82	.75	-	X
(135/225)	2	5	.67	.81	-	
	3	3	.78	.77	+	
	4	3	.76	.79	+	X
	5	3	.77	.65	+	

the new ones when differences occur is happenstance, not a merit of the old method.

In our present method of computing the dog leg we always unmask the target, which is a requirement for the collection of additional tracking data on which to base post-launch control. As we have pointed out before, the use of a dog leg to unmask so that post-launch control can be exercised does not always lead to an increase in the acquisition probability. In some cases better results are obtained by not attempting to exercise post-launch control. Unfortunately, there is no test--at least, none that we have thought of--that can be applied to the pre-launch tracking data to determine whether or not post-launch control will be effective. The decision to use or not use post-launch control when the torpedo masks the target must be based on the differences obtained with and without post-launch control, the likelihood of various engagement conditions, and the maneuvers of the target submarine that are likely to be used in the type of engagement involved. We expect to study this question in the submarine-submarine duel, using a two-sided extension of our acquisition model.

REFERENCES

(a) ADL Report NUWRES #12, "Control Modes and Acquisition Probabilities for Torpedo MK 48 (U)", Contract No. N000140-68-C-0278, January 1970, Final Report Confidential, Technical Appendices (bound separately) Unclassified.

(b) ADL Report, "Target Motion Analyses For Intercept Control (U)", presented at the USAG Seminar on Target Motion Analysis at NOL, 23 - 24 June 1971, Unclassified.

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13. ABSTRACT

A dog-leg turn may be used to unmask the target and obtain post-launch tracking data for the computation of control orders. The timing and direction of the turn, and the length of the dog leg, are examined to determine the sensitivity of the acquisition probability to these variables in the corrected-intercept mode. The length of the dog leg is computed in a way that assures that unmasking will occur and that at least one correction will be applied to the gyro course before masking recurs. Rules are determined for the computation of the length of the initial leg, the direction of the turn, and the length of the dog leg.

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